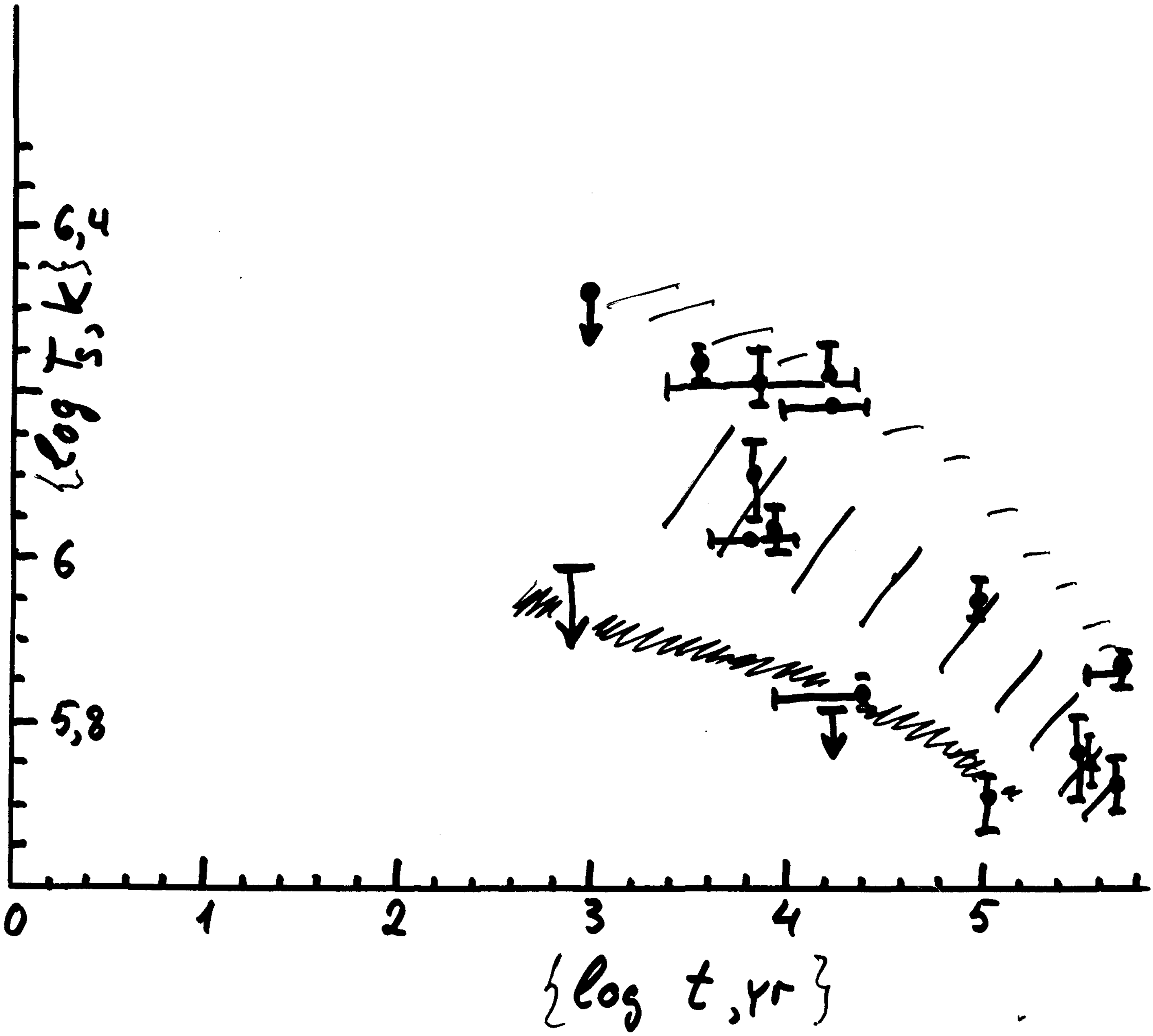
cooling of NS

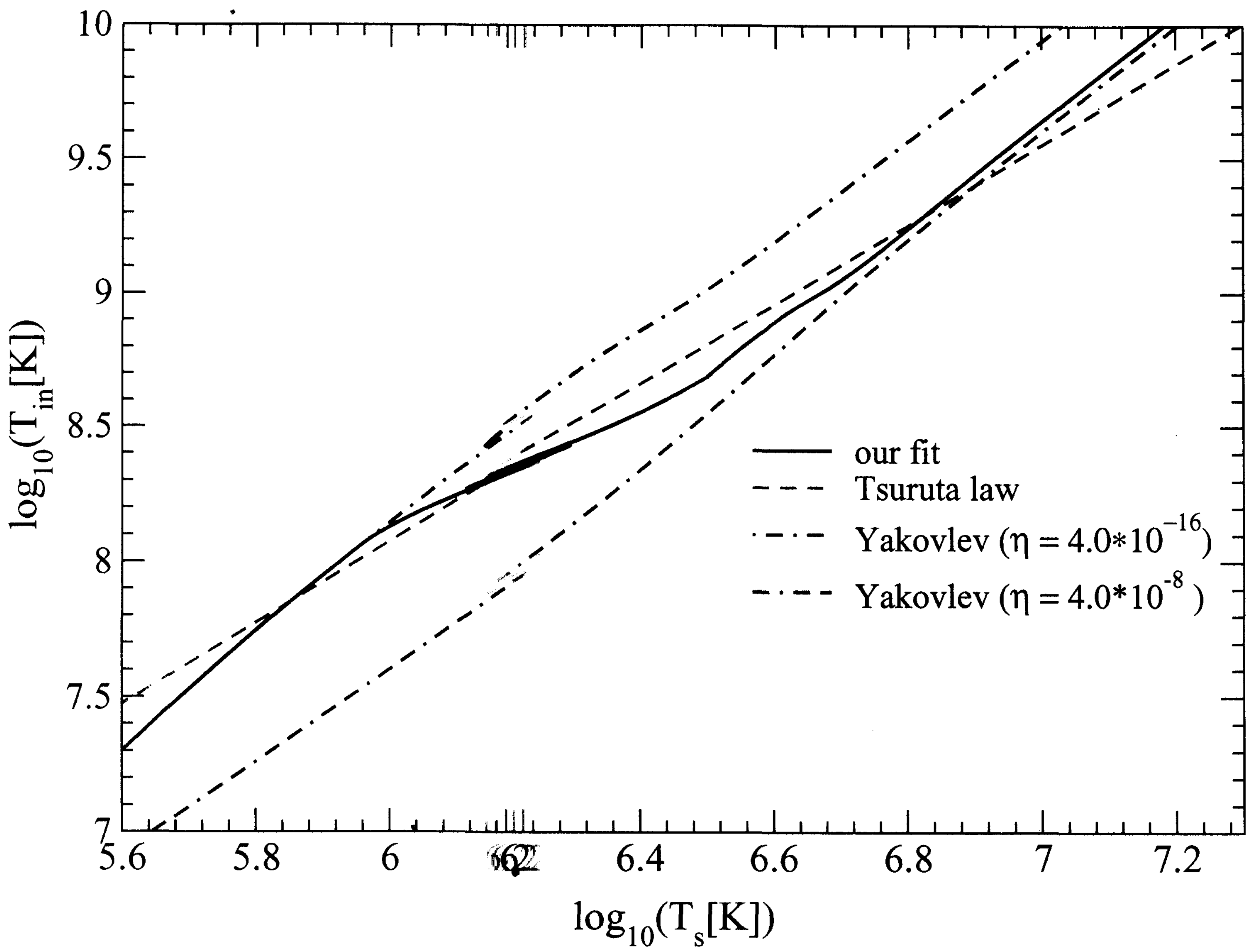


//// slow coolers

//// moderate

////// rapid

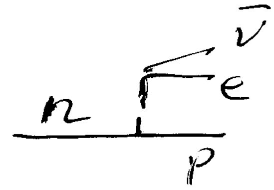
Data: three groups of points: 1) high T_s, 2) moderate, 3) low T_s. To explain both high and low T_s one needs $\gtrsim 10^4$ difference in emissivity.
Strategy: Emissivity $\epsilon(T_{in})$, specific heat C_V, thermal cond. κ from calcul., $\rightarrow T_{in}(t)$ from transport calcul., $T_s = f(T_{in})$ from calcul., $\rightarrow T_s(t) \rightarrow$ compare with $T_s(t)$ known from observations.
Standard scenario: Assume, DU, π_c, K_c processes are forbidden up to high density, not achievable in NS, assume, the main process MU: $nn \rightarrow npe\bar{\nu}$ calculated without taking into account medium effects.
$\rightarrow$ slow cooling (can explain only high T_s points).
Standard scenario+exotics := Standard scenario:+ one of DU, π_c, K_c. $\rightarrow$ can explain slow cooling and rapid cooling. Interval of NS masses to explain moderate T_s is very narrow. Why many NS are in this narow interval and why namely in this mass interval the DU, π_c, K_c are switched on?
Typical times: Black body, Neutrino trapping($\lambda_\nu < R$) $t \sim 10\ s \div hour$, $T > T_{opac} \sim MeV$, for Standard scenario:
White body, Neutrino direct radiation($\lambda_\nu > R$), $t \lesssim 10^2 \div 10^3 yr$, $T > T_c$ no superfl., $t \gtrsim 10^3 yr$ superfl.
Black body, photon cooling, $t \gg 10^5 yr$


our fit
Tsuruta law
Yakovlev (η = 4.0*10^-16)
Yakovlev (η = 4.0*10^-8)
log10(Ts[K])
log10(Tin[K])
5.6
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7
7.5
8
8.5
9
9.5
10

Assume: NO medium effects.

Typical values of emissivities

DU $\varepsilon_\nu \sim 10^{27}\, T_9^6 \ \frac{erg}{cm^3 sec}$

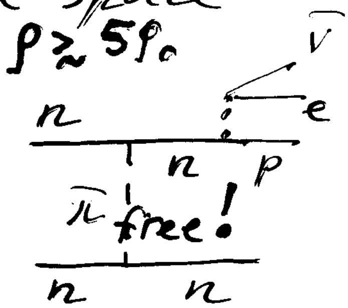


$T_9 = T/10^9 K$ — one nucleon phase space

$\rho_p/\rho > (11-14)\%$, $\rho \gtrsim 5\rho_0$

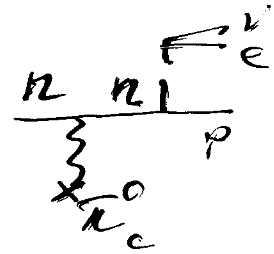
MU $\varepsilon_\nu \sim 10^{21}\, T_9^8$ — two nucleon phase space

FOPE model:



π_{cond}, K_{cond} $\varepsilon_\nu \sim 10^{27}\, T_9^6$

$\rho > \rho_{c\pi, K} \gtrsim 2\rho_0$



Superfluidity: $T < T_c$

One nucl. processes $\xi_1 \sim e^{-\Delta/T}$

two nucl. processes $\xi_2 \sim e^{-2\Delta/T}$

$\{2\Delta_n, 2\Delta_p, \Delta_n + \Delta_p\}$

„Standard" scenario

based on MU

Non-standard („Standard + exotics")

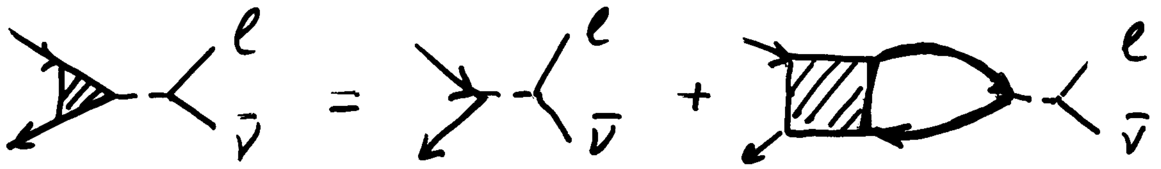
DU, π_{cond}, K_{cond}, q etc.

Above estimates need in-medium modificatio[n]

{NO free π exchange, vertex corrections, etc., new processes}$_{H}$

Renormalisation of the weak interaction

$N \neq Z$ D.V., Senatorov Sov. J. Nucl. **45** (1987) 411.



$$V_\beta = \frac{G}{\sqrt{2}}\left[\tilde{\gamma}(f')\,l_0 - g_A\,\vec{l}\,\vec{\sigma}\,\tilde{\gamma}(g')\right]$$
$(n \to p e \bar{\nu})$

$$(n \to n \nu \bar{\nu}) \quad V_{nn} = -\frac{G}{2\sqrt{2}}\left[\gamma(f_{nn})\,l_0 - g_A\,\vec{l}\,\vec{\sigma}\,\gamma(g_{nn})\right]$$

$$(p \to p \nu \bar{\nu}) \quad V_{pp} = \frac{G}{2\sqrt{2}}\left[x_{pp}\,l_0 - g_A\,\vec{l}\,\vec{\sigma}\,\gamma_{pp}\right]$$

$(l_0, \vec{l})$ - lepton current, G - Fermi coupl. c

g_A - axial-vector coupling.

spin-isospin contrib $\sim \vec{q}^{\,2}$ is small for q

and is neglected.

○ NN-correlation factors:

$$\gamma(x) = 1/[1 - 2C_0\,x\,A^R_{nn}] \;, \qquad A^R_{nn} =$$ 

$$\tilde{\gamma}(x) = 1/[1 - 4C_0\,x\,A^R_{np}]$$

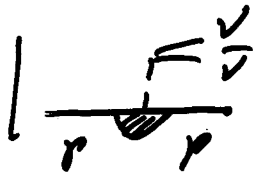
$f' = (f_{nn} - f_{np})/2$, $g = (g_{nn} + g_{np})/2$, $g' = (g_{nn} - g$

are LM-parameters.

Strong medium effect in pp-vertex:

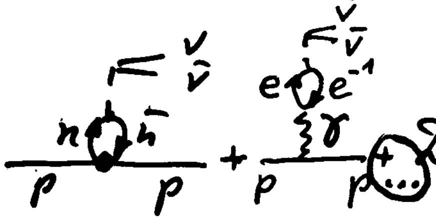
$$x_{pp} = \underbrace{c_V} - 2f_{np} A_{nn} C_0 \gamma(f_{nn})$$

$$c_V \simeq 1 - 4\sin^2\theta_W \simeq 0{,}08 \quad \text{but } x_{pp} \overset{\text{up to}}{\sim} 1 \ !$$



$\propto x_{pp}^2 \Rightarrow$ Amplification factor $\lesssim \underbrace{10^2}$!

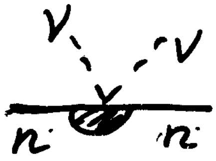
Phys. reason since:



D.V., Senatorov, Sov. J. Nucl. Ph. 45 (1987) 411,

see D.V astro-ph/10009093

L.B. Leinson, N. Phys. A687 (2001)



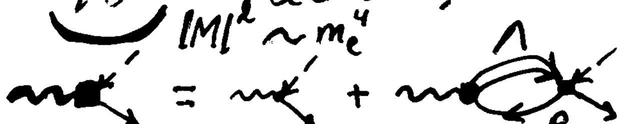
: $\gamma^{-1}(g_{nn}), \gamma^{-2}(f_{nn}) \simeq 0{,}7 - 0{,}9$

for $\omega \simeq q \sim T$

in strong coupl. vert: $\gamma(g_{nn}) \simeq 1/3$ for $\omega = 0, q \simeq p_F$

Weak coupling vertex renormalisation in $\bar{\nu}_e \to e^+ + K^-_{medium}$ on nucleus increases the rate

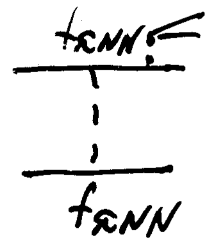
by $\underbrace{10^5}_{|M|^2 \sim m_e^4}$ factor ! Kolomeitsev, D.V. Phys. Rev 66([illegible]) 034[illegible]



[in some processes – vertex suppression,
in some – enhancement.]

Simple arguments against use of free OPE (FOPE) for $\rho \gtrsim \rho_0$

FM(1979)

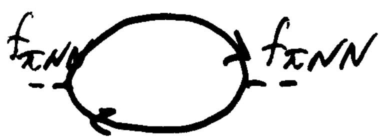
Born approx: $|M|^2 = \Big|$ 

$\Big|^2$

Argumentation from D.V., Senatorov & JETP (1986):

Using pert. th. in $f_{\pi NN}$ up to 2 order one should consider pion energy also up to $f_{\pi NN}^2$

$$\omega^2 = m_\pi^2 + k^2 + \Pi^0(\omega, k)$$

$\Pi^0 =$ 

Perturb. th. in dimensionless param. $f_{\pi NN} k \gtrsim 2$

$f_{\pi NN} \simeq \frac{1}{m_\pi}$, $k \simeq P_F$, $P_F(\rho_0) \simeq 2 m_\pi$???

Puzzle:

$N=Z$,  $= \Pi^0 = -\frac{2 m_N p_F}{\pi^2} f_{\pi N}^2 q^2 \Phi(\omega,k) \underset{\substack{\omega=0 \\ k\simeq p_F}}{\simeq} -\frac{2 m_N p_F k^2}{\pi^2} f_{\pi N}^2$

$q^2=\omega^2-k^2$

spectrum:

$$\omega^2 = m_\pi^2 + k^2 + \Pi^0_R(\omega,k) \underset{\substack{\omega\simeq 0 \\ k=p_F}}{\overset{\rho=\rho_0}{=}} m_\pi^2 - 1{,}4\, p_F^2 + \beta\omega i \overset{\omega=0}{\simeq} -1{,}8\, m_\pi^2 < 0 \,!$$

$\beta>0$ $\omega \simeq i|\alpha|$

$$\varphi \sim e^{-i\omega t} \sim e^{+\frac{1{,}8}{\beta} m_\pi^2 t} \to \infty$$

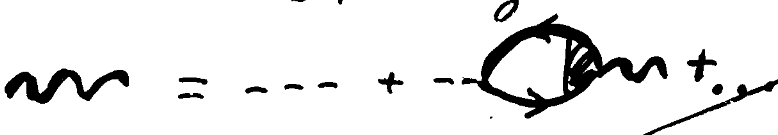
π-cond at $\rho \gtrsim 0{,}3\rho_0$ in contradiction with exp. data! There is no π cond. even at ρ_0 at $N=Z$

Solution of the puzzle:

weak coupl. vertex enhancement $\gamma_W^{-1}(\omega=q) \simeq 0{,}7-0{,}9$

strong coupl. vertex suppr. $\gamma(\omega\simeq 0, k=p_F) \simeq (0{,}3-0{,}5)$

pion softening



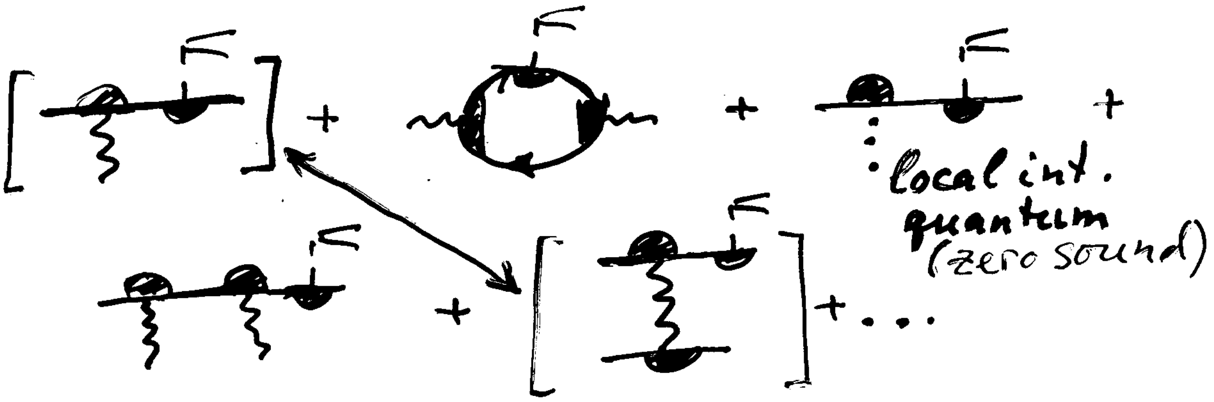
$\Pi =$  $\simeq \Pi^0 \cdot \gamma(g') \simeq -k^2 \Rightarrow \tilde{\omega}^2 \simeq m_\pi^2,\ \omega^2>0$ for $\rho=\rho_0$

No π-cond. for $\rho=\rho_0$ due to appropriate vertex suppression.

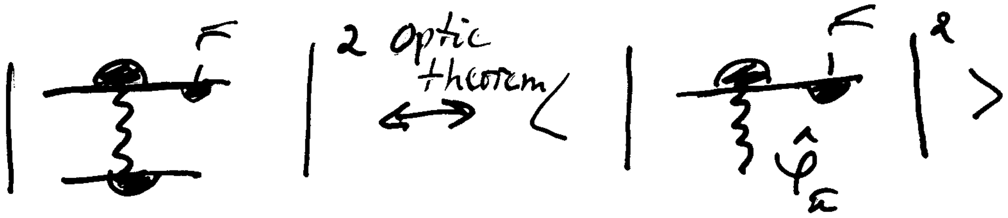
Problem of separation of different processes

D.V., Senatorov JETP Lett 40 (1984), JETP 90 (1986)

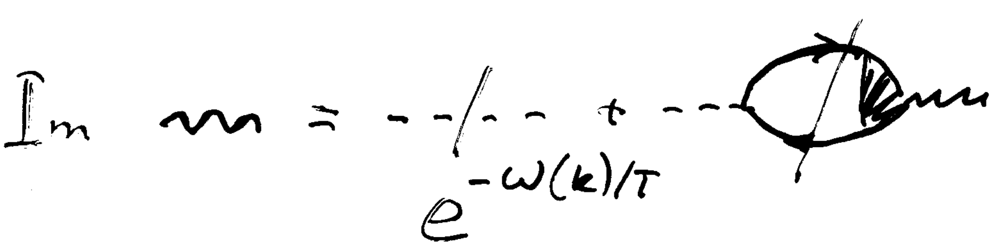
In medium many reaction channels are opened

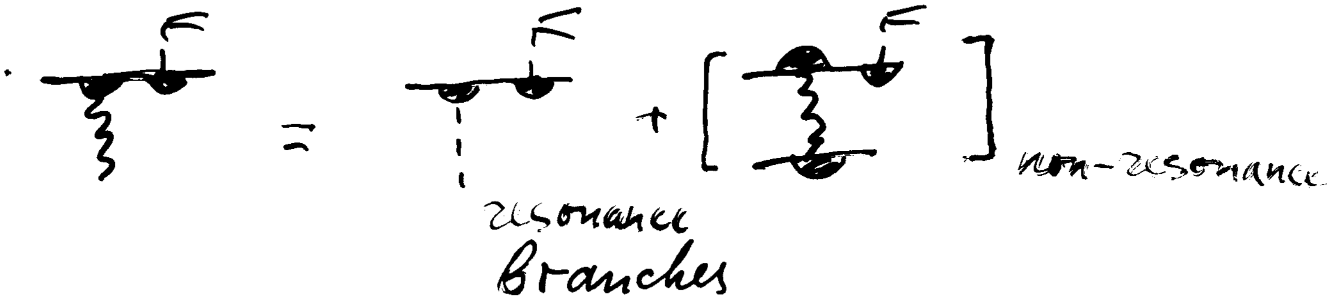


[ ] - double counting !



$$i\langle\varphi^{+}\varphi\rangle = -\frac{2\,\mathrm{Im}\,G^{R}}{e^{\frac{\omega}{T}}-1} = iG^{-+}$$ (Kubo-Schwinger-Martin)





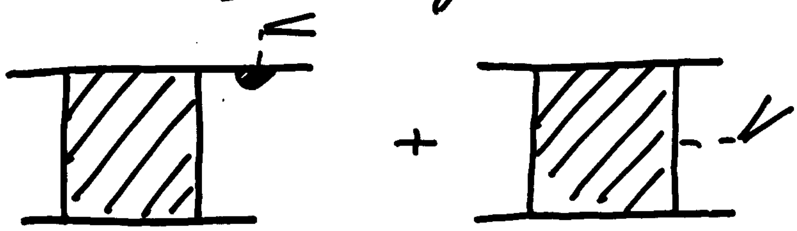
1+

MU in medium (MOPE)

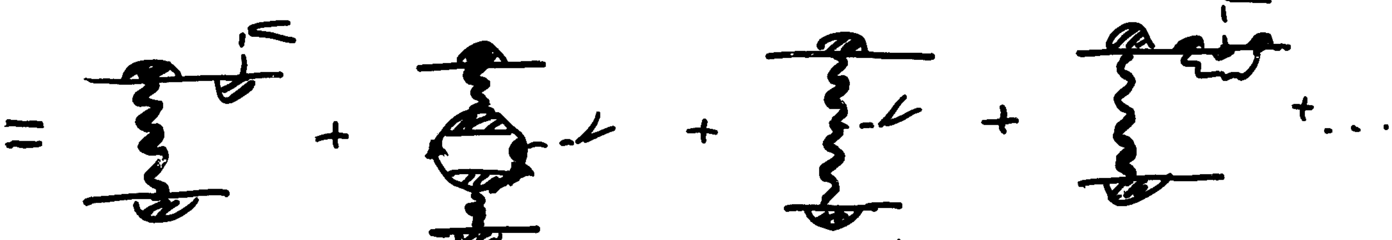
$T_{c\Delta} < T < T_{opac}$ (~ MeV)

$T/\varepsilon_{FN} \ll 1$, $\Gamma_N \equiv -2\,\mathrm{Im}\,\Sigma_N^R \sim \pi^2 \varepsilon_F \left(\frac{T}{\varepsilon_F}\right)^2 \ll T$.

Nucleons are good QP for $T < T_{opac}$

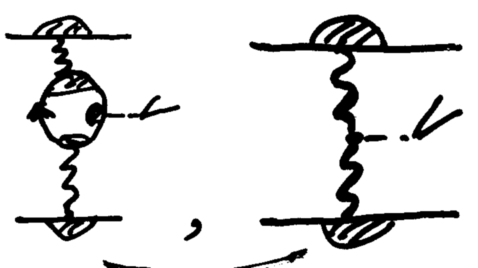


= (In medium are opened many reaction channels!)

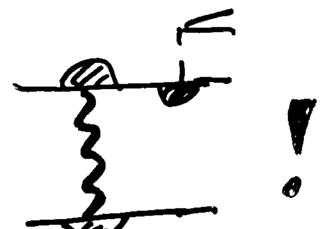


(1) (2) (3)

Main contrib. comes from (3), (2):



for $\rho \gtrsim \rho_0$ not from (1)



(generaliz. of FOPE) !

medium OPE

$$\alpha_\nu = \frac{\varepsilon_\nu[\text{MOPE}]}{\underset{\text{free OPE}}{\varepsilon_\nu[\text{FOPE}]}} \simeq 10^3 \frac{\gamma^4(g')}{\underbrace{\tilde{\omega}^8(k=p_{Fn})}_{\text{pion gap}}} \left(\frac{\rho}{\rho_0}\right)^{10/3}$$

For $\rho = \rho_0$ $\alpha_\nu \lesssim 10$!

α_ν increases with ρ! Sharp density dependence.

Only for $\rho \ll \rho_0$ results MOPE and FOPE coincide

ut T-matrix result differs from free OPE ev. at $\rho \ll \rho_0$

see argumentation of Blaschke, Röpke, Schulz, Sedrakian, D.V. MNRAS 273 (1995) 576, Hanhart, Phillips, S. Reddy, astro-ph/0003445 (2000).

Non-eq. Green's function technique

Advantages:

- principally simple

does not decouple

$$iG^{--}_{12} = \langle n|\hat{T}\hat{\Psi}_1\hat{\Psi}_2^+|n\rangle \overset{\text{interaction picture}}{=} \langle n|\hat{S}^{-1}\hat{T}\hat{\Psi}_{01}\hat{\Psi}_{02}^+\hat{S}|n\rangle$$

arbitrary non.eq. state

$$\hat{S} = \hat{T}e^{-i\int_{-\infty}^{\infty}\hat{V}_0(t)\,dt}, \quad \hat{S}^+ = \hat{S}^{-1} = \hat{T}^+ e^{i\int_{-\infty}^{\infty}\hat{V}_0(t)\,dt}$$

$\Rightarrow$ pairings from $\hat{T}$ to $\hat{T}$, $\hat{T}^+$ to $\hat{T}^+$, $\hat{T}$ to $\hat{T}^+$

$iG^{--}_{12} = \langle T\hat{\Psi}_1\hat{\Psi}_2^+\rangle$ time ordered

$iG^{++}_{12} = \langle T^+\hat{\Psi}_1\hat{\Psi}_2^+\rangle$ anti-time ordered

$iG^{-+}_{12} = \underset{\text{Bose}}{\overset{\text{Fermi}}{\mp}}\langle\hat{\Psi}_2^+\hat{\Psi}_1\rangle$ $\quad (iG^<)$

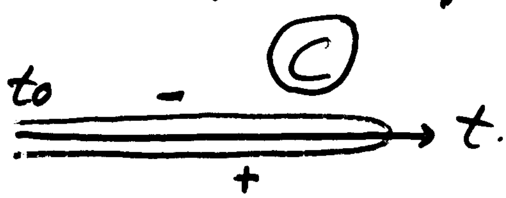
$iG^{+-}_{12} = \langle\hat{\Psi}_1\hat{\Psi}_2^+\rangle$

Wigner densities

Matrix

Schwinger-Keldysh contour

$$G^{ij} = \begin{pmatrix} G^{--} & G^{-+} \\ G^{+-} & G^{++} \end{pmatrix}; \quad G_C:$$



pioneering works:

Schwinger J. Math Phys. 2 (1961) 407

Kadanoff, Baym, Quantum Stat. Mech., Benjamin

Keldysh, Sov. Phys. JETP 20 (1965) 1018

Nucl. Ph.: Danielewicz Ann. Ph. 152 (1984) 239, 305

Optic theorem formalism in non-eq closed diagr. techniq

D.V., Senatorov Sov J. Nucl. Ph. 45 (1987) 411
J. Knoll, D.V. Ann. Phys. 249 (1996) 532

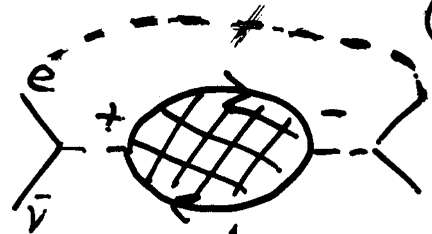
$$S \simeq 1 - i\int_{-\infty}^{\infty} \hat{T}\{V_w(x_0)\, S_{nucl}(x_0)\}\, dx_0 + \dots$$

└ up to 1 order in weak coupl.

White body radiation:

$$\mathcal{E}_\nu = 2\int \omega_\nu \left(-i\Pi^{-+}_{\bar\nu e}\right)(1-n_e)\,\frac{d^3 q_e}{(2\pi)^3\, 2\omega_e}\,\frac{d^3 q_{\bar\nu}}{(2\pi)^3\, 2\omega_\nu}$$

$-i\Pi^{-+}_{\bar\nu} =$



e ← integration over e q.p. $(1-n_e)$

$\bar\nu$-free

↑ full summation of nuclear processes

gain term in generalized kin eq for $\bar\nu$.

When QPA for N is valid ($\omega_{\nu e} \gtrsim T \gg \Gamma_N \sim T^2/\varepsilon_F$) simple cutting procedure:

- expansion in QP ($G^{-+}G^{+-}$)

$$G^{-+}_N = -2i n_p\, \mathrm{Im}\, G^R_N, \qquad n_p = \frac{1}{e^{\frac{\varepsilon_p-\mu_N}{T}}+1},$$

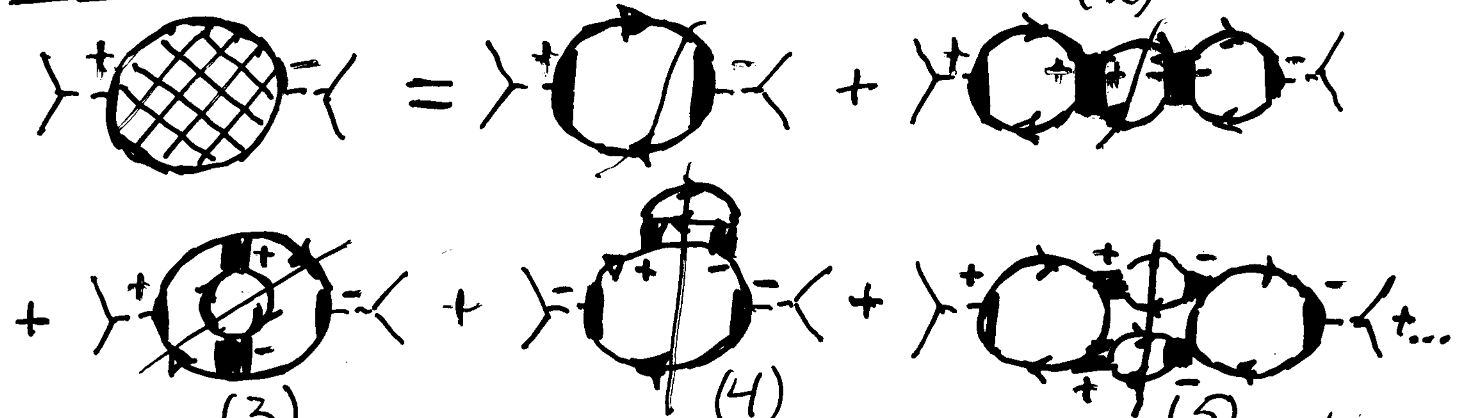
$$\mathrm{Im}\, G^R_N = -\pi\,\delta\left(\varepsilon+\mu_N-\varepsilon^0_p-\mathrm{Re}\,\Sigma^R_N(\varepsilon+\mu_N,\vec{p})\right) \Rightarrow \text{cut!}$$

- each ($G^{-+}G^{+-}$) brings $(T/\varepsilon_{FN})^2 \ll 1$
- $G^{--} = G^R + G^{-+} \simeq G^R$, $G^{++} = G^{+-} - G^R \simeq -G^R\,\left(\mathrm{const} + O\left(\frac{T}{\varepsilon_{FN}}\right)^2\right)$

leading contrib. in T is easily obtained

Diagrammatic decomposition in terms of QP nucleon Green's functions G^{-+}

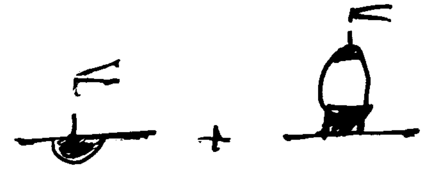
<u>Series in number of G^{-+}:</u> (1) (2)

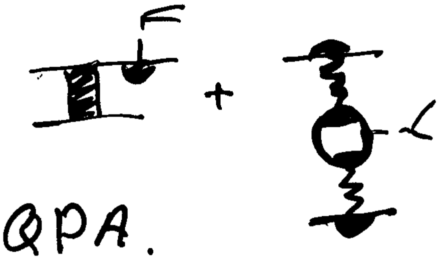


(3) (4) (5)

∫ QP cut which relates closed diagrams to $\sum |M|^2$ result.

 are $-+$, $+-$ irreducible

After cut: G^{-+}: (1), (2) ⟺  one nucleon processes

$[G^{-+}]^2$: (3)–(5) ⟺  two nucl. processes

(4) is reducible, added only in QPA.

Within QPA both ($\sum |M|^2$ and Optic theorem Formalism) coincide

Advantages of optic th. formulation:

- All is included in $\Gamma_{NN}^{(i,j)}$ amplitude ($i,j=(+,+)$ or $(-,-)$) (not necessary to consider different processes – one can deal with full NN-interaction) less model dependent
- Each $G^{-+}G^{+-}$ product brings $(T/\varepsilon_F)^2$ small parameter.
- no asymptotic states are involved
- valid for arbitrary non-equilibrium
- is easily generalized to systems with pairing
- is generalized beyond the QPA for N.

Systems with the pairing

Let $T < T_{c\Delta}$. D.V., Senatorov Sov. Nucl. Phys 45 (1987) 411

QPA:

$$G^{-+} = 2\pi i\, n_\omega \{ u_p^2\, \delta(\omega - \varepsilon_p) + v_p^2\, \delta(\omega + \varepsilon_p) \}$$

$$G^{+-} = -2\pi i\, n_{-\omega} \{ u_p^2\, \delta(\omega - \varepsilon_p) + v_p^2\, \delta(\omega + \varepsilon_p) \}$$

$$(F^+)^{-+} = \frac{\pi i \Delta}{\varepsilon_p}\, n_{-\omega} \{ \delta(\omega + \varepsilon_p) - \delta(\omega - \varepsilon_p) \}$$

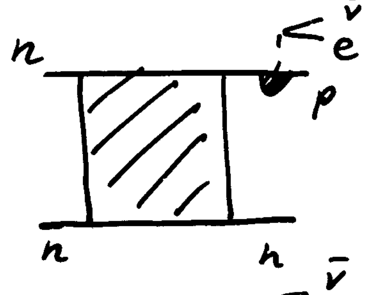
$$iG^{ij} = j \xrightarrow[p]{} i\,, \quad iF^{ij} = j \underset{-p\quad p}{\longleftrightarrow} i\,, \quad iF^{+\,ij} = j \underset{-p\quad -p}{\rightarrow\!\leftarrow} i$$

$$u_p^2 = \frac{\varepsilon_p + \varepsilon_{p0}}{2\varepsilon_p}\,, \quad v_p^2 = \frac{\varepsilon_p - \varepsilon_{p0}}{2\varepsilon_p}\,, \quad \varepsilon_p^2 = \varepsilon_{p0}^2 + \Delta^2.$$

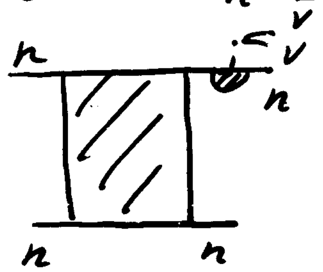
Bogolyubov QP factors

NS cooling for $T < T_{c\Delta}$

MU:



$$\varepsilon_\nu^{MU} \sim e^{-(\Delta_n+\Delta_p)/T}$$



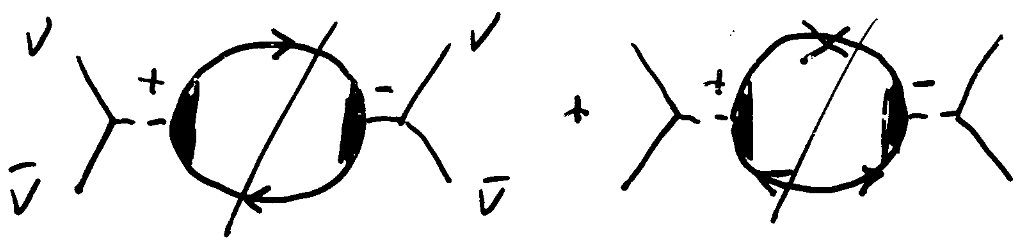
$$\varepsilon_\nu^{\nu\bar{\nu}} \sim e^{-2\Delta_n/T}$$

DU:

Naively: 

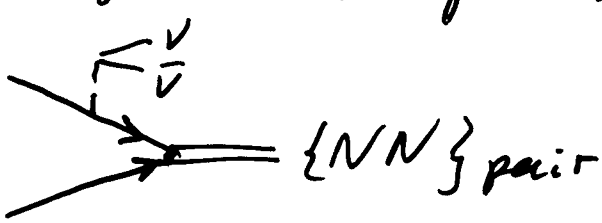
, were forbidden in absence of pairing
were droped

Optic theorem formulation:

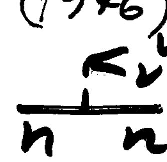


Non-trivial $(u_p v_p)^2$- contribution!

Physically: PFB-processes



• Flowers, Ruderman, Sutherland ApJ 205 (1976) –
Bogolyubov Ψ-tech., s-pairing nn:

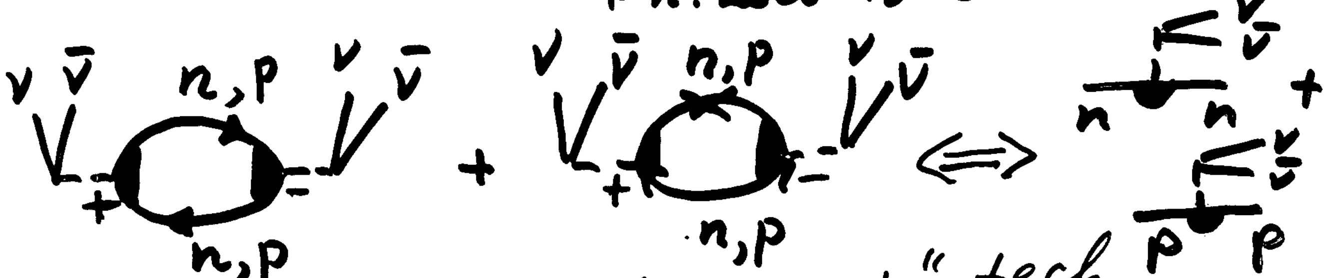


no med. efs. →
Correct general expr., incorrect numerical est. and incorrect asympt. expr.

$$\varepsilon_\nu^{FRS} \sim 10^{20} T_9^7 e^{-2\Delta/T}, \quad T \ll \Delta$$

{was forgotten}

• D.V., Senatorov Sov. J. Nucl Ph. 45 (1987)
Ph. Lett B184 (1987)



as demonstration of our „−+" tech.
incorrectness in vertex pre-factor (~1 factor)
Not important due to uncert. in correl. factors

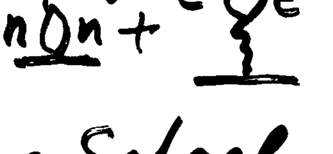
$$\varepsilon_\nu^{VS} \sim 10^{28} \left(\frac{\Delta}{MeV}\right)^7 \sqrt{\frac{T}{\Delta}}\, e^{-2\Delta/T}\, V, \quad T \ll \Delta$$

estimate is valid both for p and n,
for S and P pairing.

$$\left[\begin{array}{l}\Delta \simeq 0{,}5\,MeV, T \simeq 0{,}1\,MeV \\ \varepsilon_\nu^{FRS}/\varepsilon_\nu^{VS} \sim 10^{-5} \sim \dfrac{\varepsilon_\nu^{FRS}}{\varepsilon_\nu^{VS}}\end{array}\right.$$

$V_n \sim 1, \quad V_p \simeq \varkappa_{pp}^2 \sim 1$

$$\varkappa_{pp} = c_V - \underbrace{2 f_{np} A_{nn} C_0 \Upsilon(f_{nn})}_{\text{main term}}, \quad c_V = 0{,}006 \text{ for vac. vert.}$$



(Leinson N. Ph. A687 (2001))

• Schaab, Sedrakian A., Weber, Weigel, D.V. (199?)
included in code and called PFB processes

$\gamma^2(1+3g_A^2) \to \xi_1\gamma^2(f_{nn})+\xi_2\gamma^2(g_{nn})g_A^2$

D.V., Senatorov

$\xi_1=1, \xi_2=0$ S pairing

Pl. Lett

$\xi_1=2/3, \xi_2=4/3$ P

$$
\begin{aligned}
\mathscr{E}_{\mathrm{n}}^{\nu\bar{\nu}} &= \tfrac{128}{15} G^2 \gamma^2 \\
&\times \left[\left(1 + 3g_{\mathrm{A}}^2\right) p_{\mathrm{F}}^{\mathrm{n}} m_{\mathrm{n}}^* \Delta_{\mathrm{n}}^7 / (2\pi)^5 \right] I(\Delta_{\mathrm{n}}/T) \\
&\simeq 6.6 \times 10^{28} \gamma^2 (\rho/\rho_0)^{1/3} \\
&\times (m_{\mathrm{n}}^*/m_{\mathrm{n}})(\Delta_{\mathrm{n}}/\mathrm{MeV})^7 I(\Delta_{\mathrm{n}}/T), \\
&T < T_{\mathrm{cr}}^{\mathrm{n}}, \\
I(x) &= \int_0^\infty (\mathrm{ch}\; y)^5 [\exp(x\; \mathrm{ch}\; y) + 1]^{-2}\, \mathrm{d}y, \\
I(x \gg 1) &\simeq \mathrm{e}^{-2x} x^{-1} \sqrt{\pi/4}, \\
I(x \ll 1) &\simeq 0.60 x^{-5}. \qquad (21)
\end{aligned}
$$

Analogous expressions can be obtained for the emissivity of the process $\mathrm{p} \to \mathrm{p}\nu\bar{\nu}$. Particular attention has to be paid to the large numerical factor $\sim 10^{28}$ in (21) and to the comparatively weak dependence of $\mathscr{E}_{\mathrm{n}}^{\nu\bar{\nu}}$ on the nucleon correlation factor γ. So, according to the estimate (21) the reactions $\mathrm{N} \to \mathrm{N}\nu\bar{\nu}$ are of primary importance in the problem of cooling of a superfluid neutron star.

We are indebted to V.F. Dmitriev, A.M. Dyugaev, A.B. Migdal, and V.M. Osadchiev for stimulating discussions.

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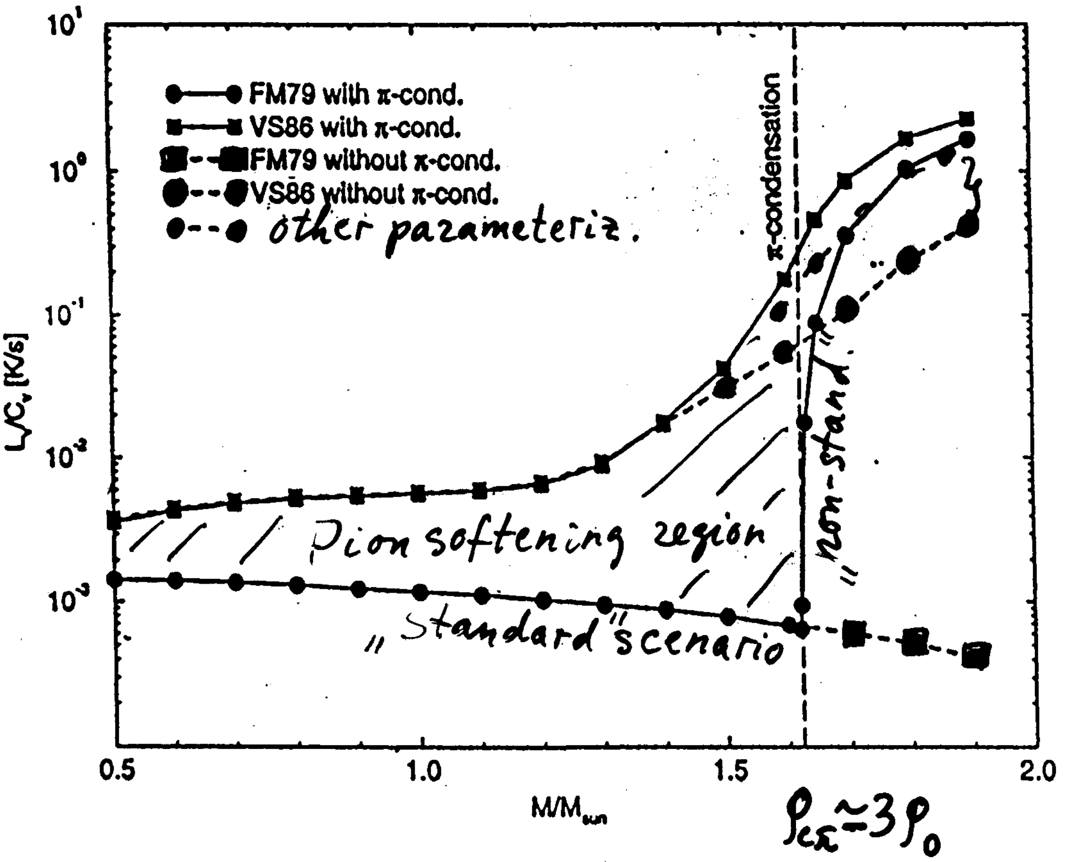
$T = 0{,}3 \cdot 10^9 K$



from Schaab, D.V., Sedrakian, Weber, Weigel
Astron. Astroph. 321 (1997) 591

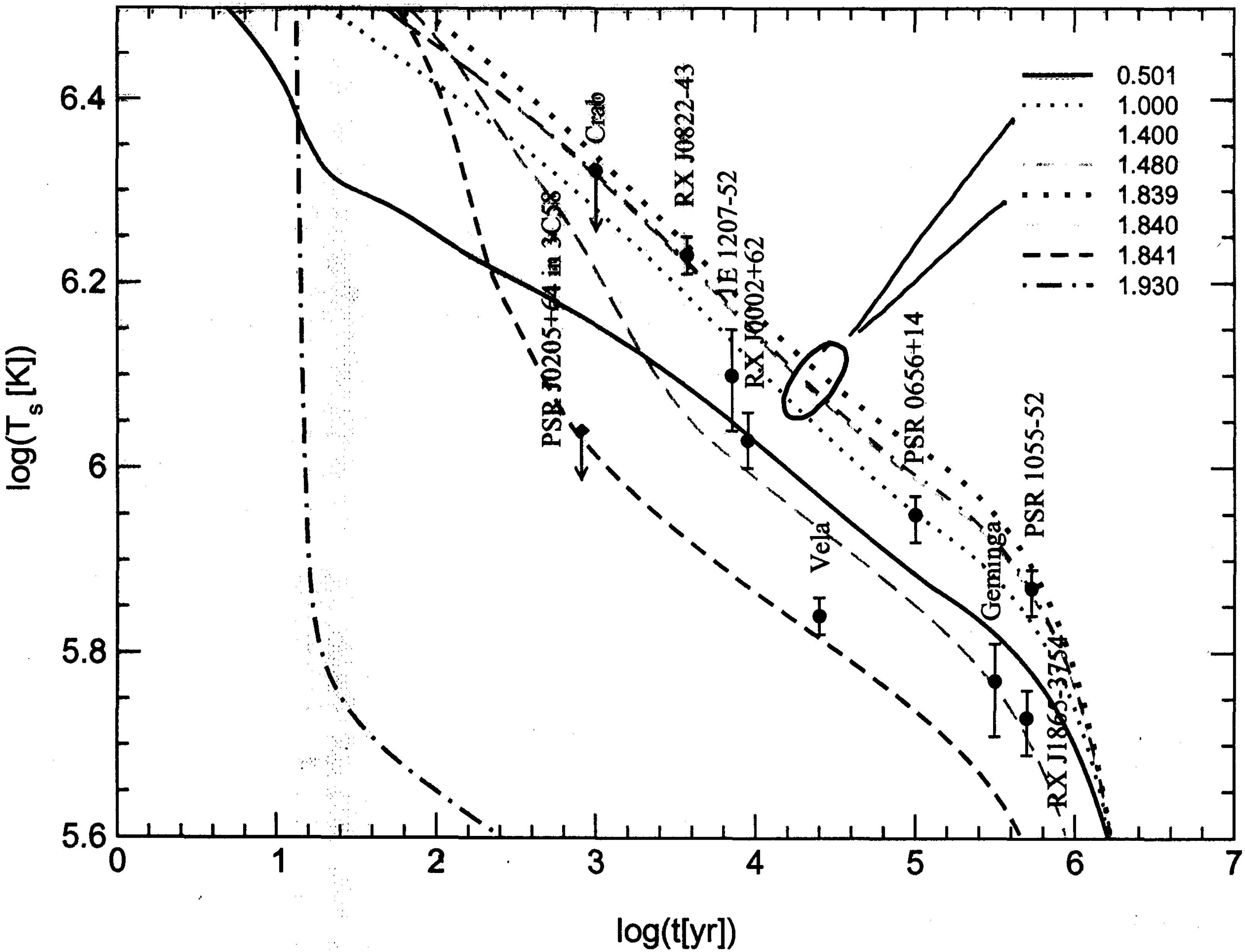
$C_v \dot{T} = -L$, $t_{ch}^{-1} \sim \frac{L}{C_v}$

Numerical analysis of role of medium ef.:
D. Blaschke, H. Grigorian, D.V. astro-ph/0403170

- EOS Argonne V18+δv+UIX* {HHJ param.}
  $n_c^{DU} \simeq 5{,}19 n_0$, $M_c^{DU} \simeq 1{,}839 M_\odot$
- heat transport, „$\varkappa$" affects $t \lesssim 10^3$ y
- medium ef-s (including pion softening) in C_V, ε,
- superfluidity
- a) π-cond, $n_c^{PU} \simeq 3 n_0$ б) no π-cond., only π-soft
- unknown parameters were widely varied

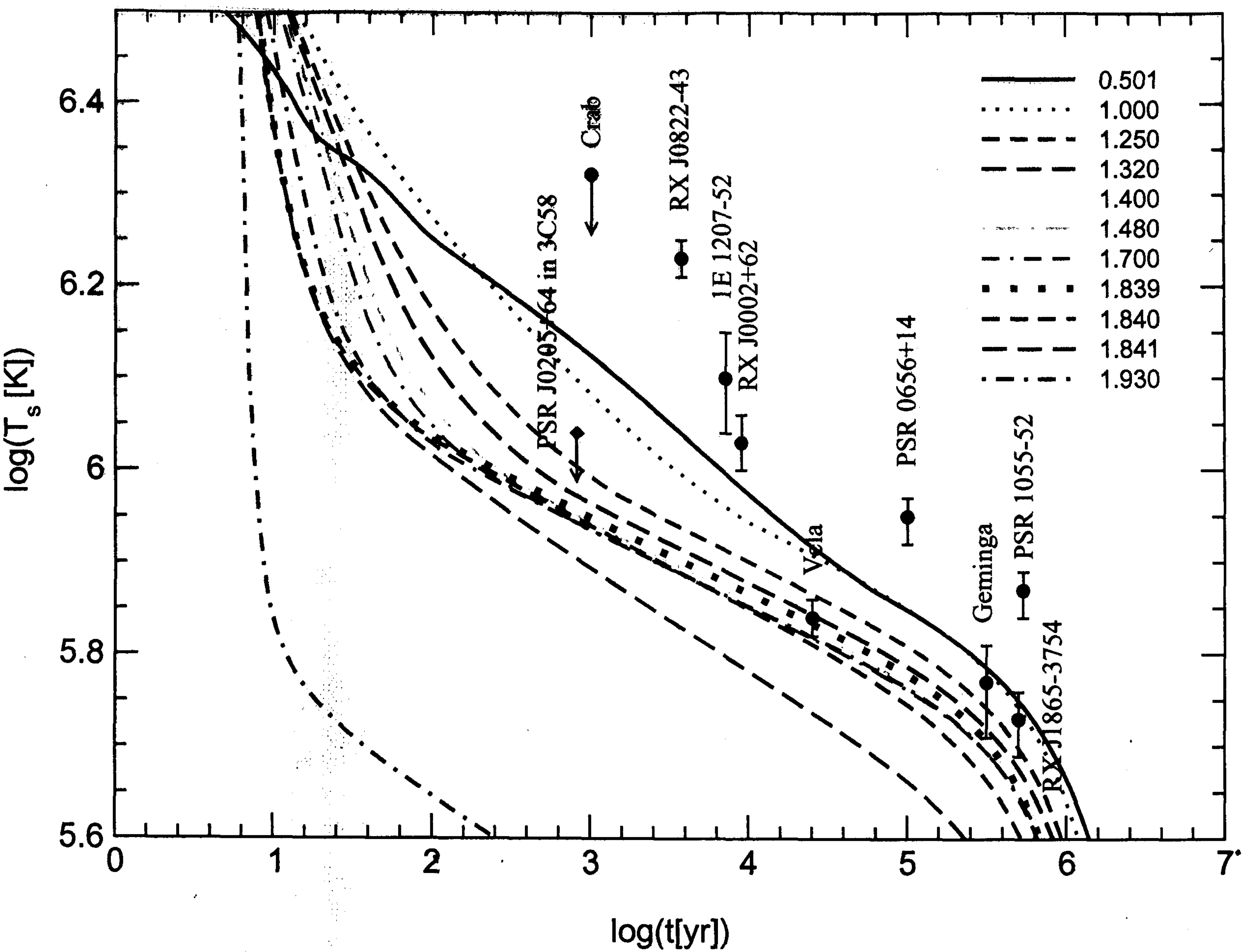
- reheating mechanism (cf. S. Tsuruta 2004) was not included (m.b. important for old objects)
  {K_c, q, hyperons, etc. }

No med. ef. and PU, normal matter

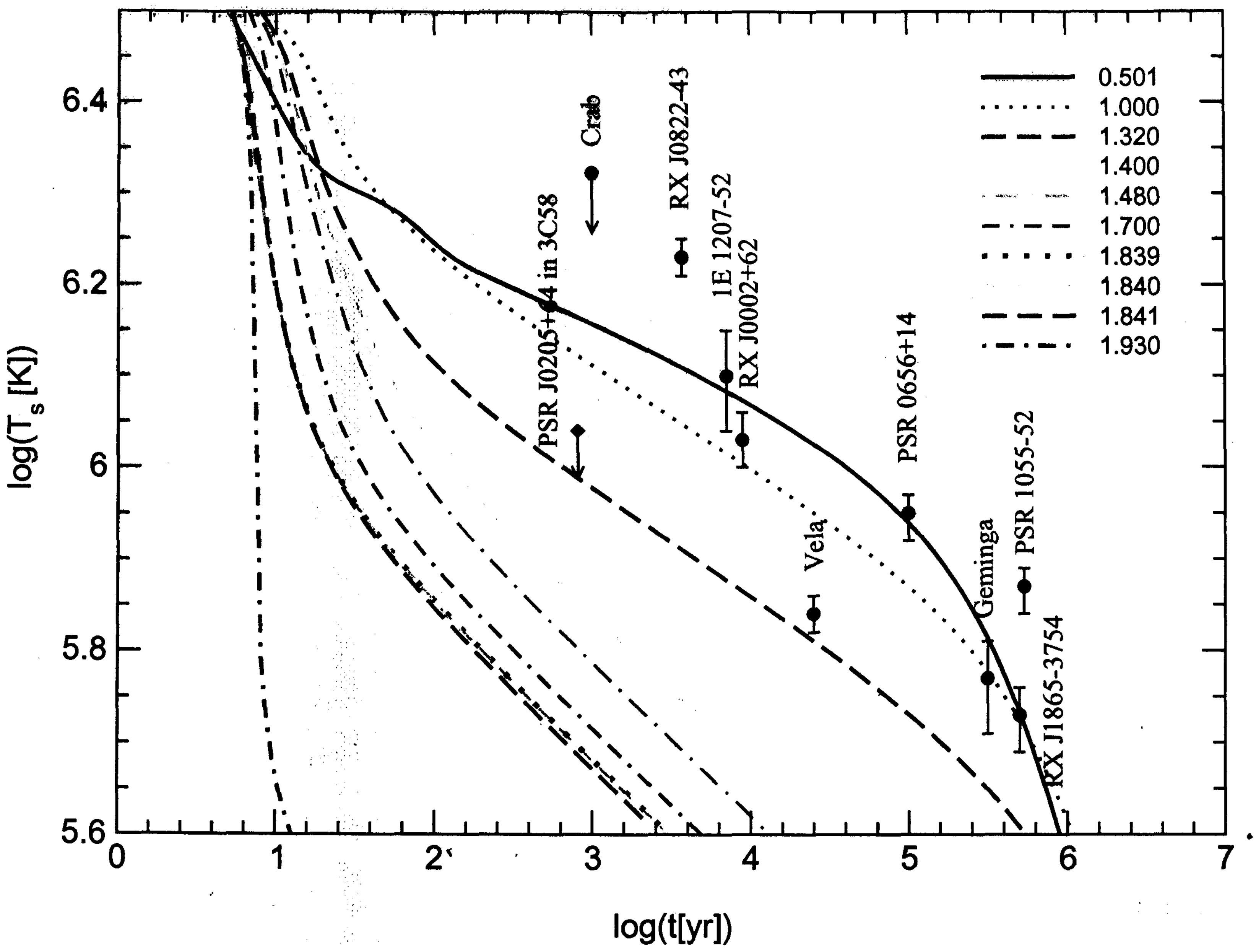


} DU

„med. ef.", no PU, normal



med ef-s, including π-cond, $n_c \simeq 3 n_0$, normal



Medium ef-s and possibility of PU,
although they regulate NS mass dependence
show too rapid cooling for Normal matter ca

⇒ Normal matter case seems to be
rooled out

Pairing gaps:

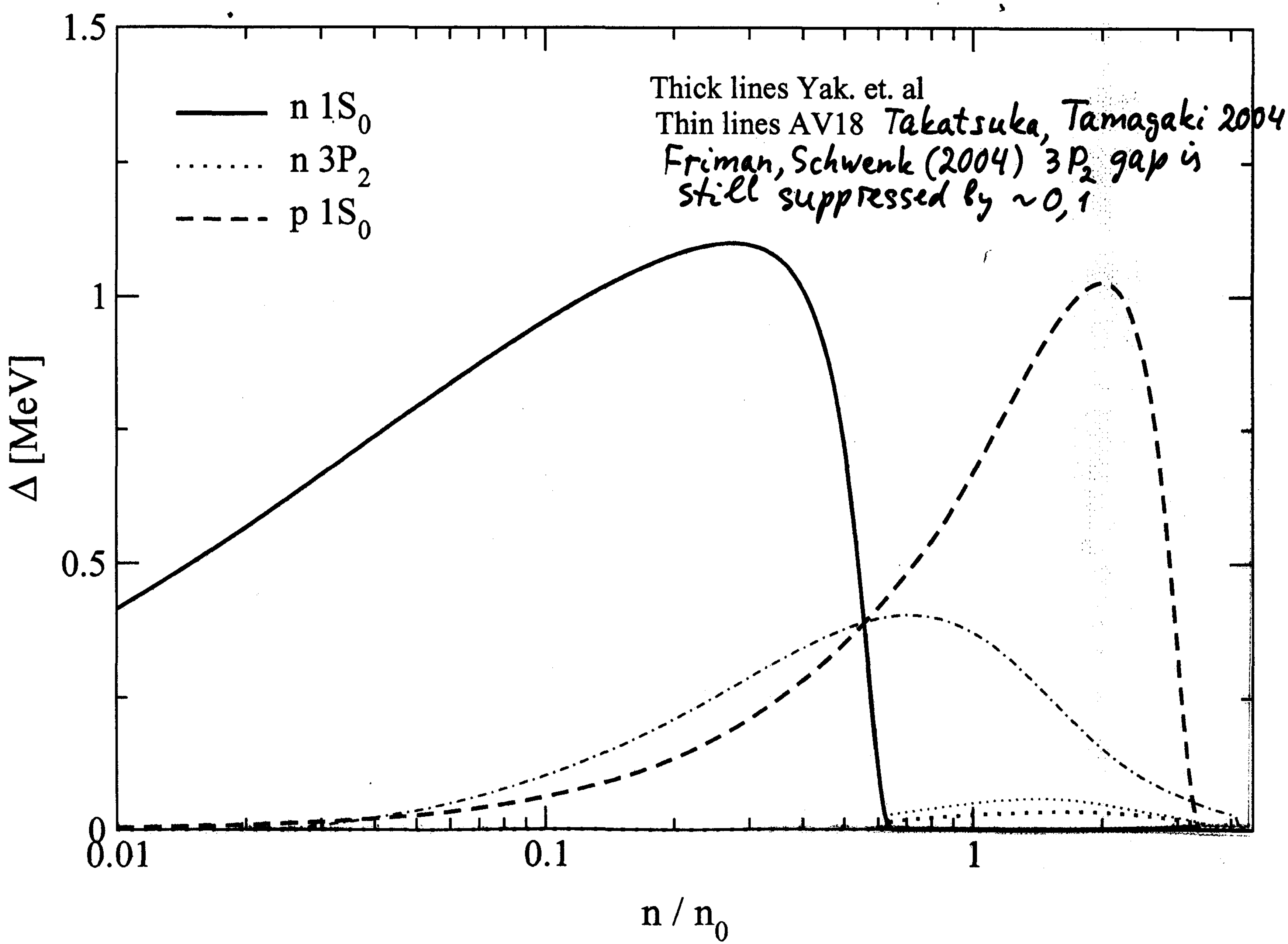
nn pairing and pp pairing. No np pairing ($E_{Fn} \gg E_{Fp}$). Superfluid gaps are poorly known.

$\Delta \simeq 2E_F \exp(-1/(NV)), \quad N = m^* p_F/\pi^2,$

V is medium modified interaction (poorly known, + in exponent) in particle-particle channel

pp pairing in $1S_0$ state: $\Delta \lesssim MeV$,
nn pairing in $1S_0$ state for $0.1\rho_0 \lesssim \rho \lesssim \rho_0$, $\Delta \lesssim MeV$,

nn pairing in $3P_2$ state for $\rho \gtrsim \rho_0$, Medium effects decrease gaps . $\Delta \lesssim 30 keV$ (Friman, Schwenk 2004). (as we also see from local inter. corrected by loops) (Khodel, Clark, Takano, Zverev (2004). $3P_2$ gap is large, $\Delta \lesssim 10 MeV$. Medium eff. increase $3P_2$ as conseq. of pion softening? Model is oversimplified but it is a challenge to solve this puzzle (our preliminary result: KCTZ may work only near n_c)
$\leftrightarrow$ extremely important for NS cooling.



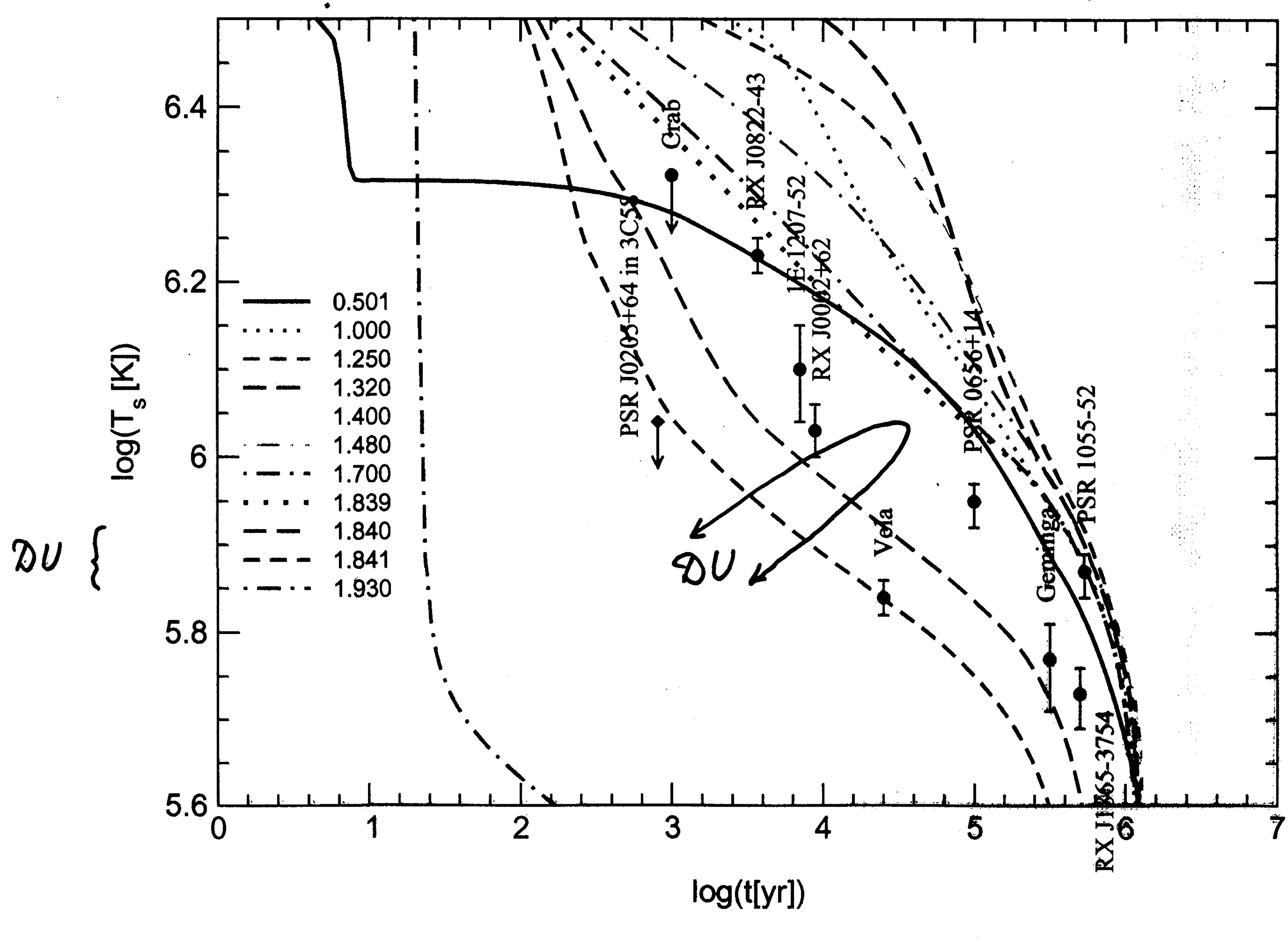
1.5
1
0.5
0
0.01
0.1
1
Δ [MeV]
n / n0
n 1S0
n 3P2
p 1S0
Thick lines Yak. et. al
Thin lines AV18 Takatsuka, Tamagaki 2004
Friman, Schwenk (2004) 3P2 gap is
still suppressed by ~0,1

Further suppression of gaps due to medium ef-s is allowed (Lombardo, Schulze 2000, Schwenk, Friman 2003)

↳ P wave gaps $\lesssim 10\,\mathrm{keV}$

$\Rightarrow 0{,}1 \times {}^3P_2$ gap factor

superfl., no med. ef. and rU
gaps: $0,1 \times 3P_2$ gap cf. Yak et al (2003)



„Standard scenario"

- only „slow cooling points" are explained
- „intermediate cooling points" can be explained by DU at price $M > 1{,}839\, M_\odot$
- „intermediate to rapid cooling points"
  M between $(1{,}839 \div 1{,}841)\, M_\odot$
  very narrow interval
- $M = (0{,}1 \div 0{,}5)\, M_\odot$ need unusual scenario of NS production. (In standard mechanism $M > 1\, M_\odot$) see S. Popov (2004)

Only „slow cooling data" can be reasonably explained

superfl, med. ef., without PU
gaps: 0,1 × $3P_2$ gap ff. Yak et al (2003)

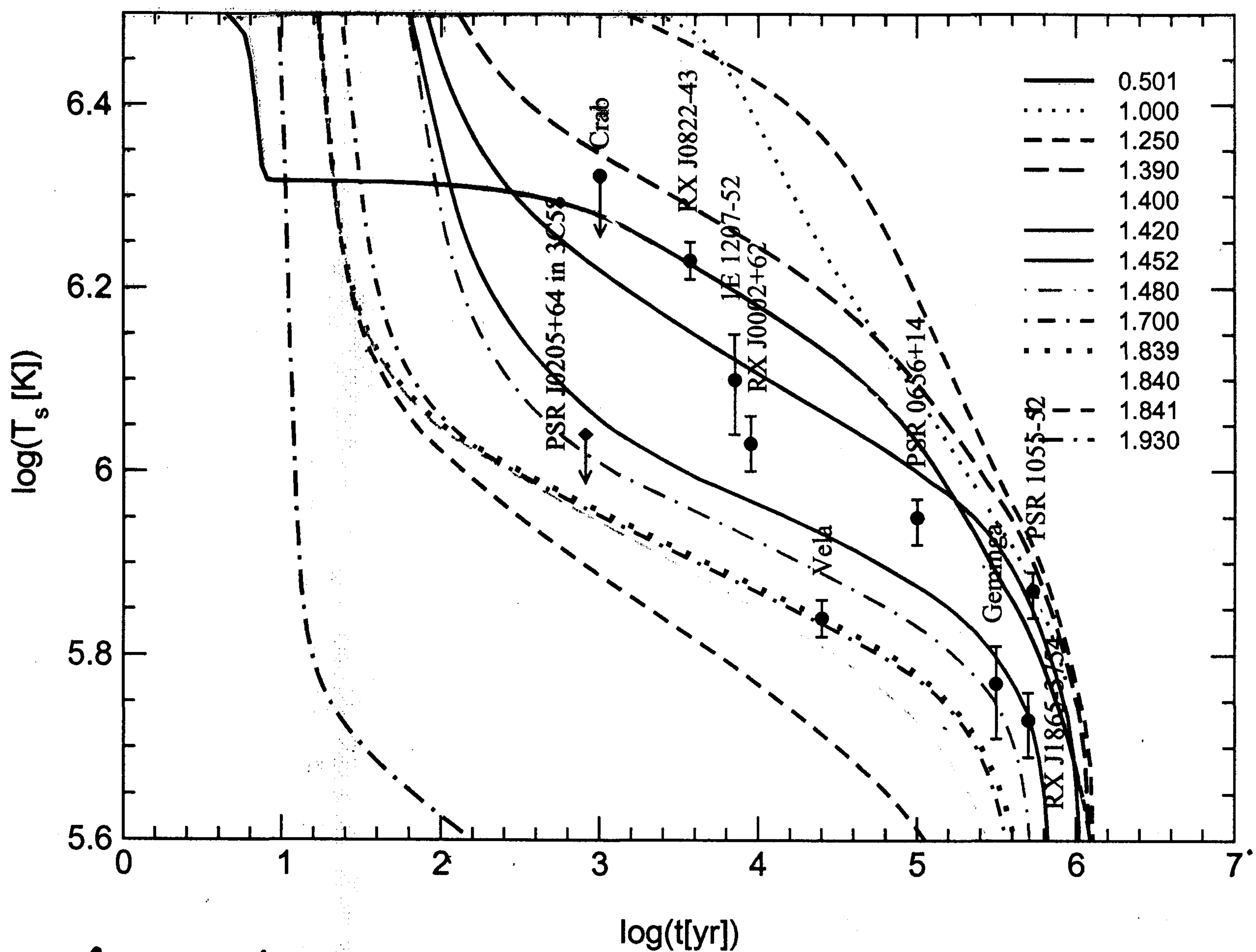


fig12, BGV (2004) $M = 1,39 \div 1,84 M_{\odot}$

superfl., med ef. + PU
0,1 × $3P_2$ gap, + Yak. et al (2003)

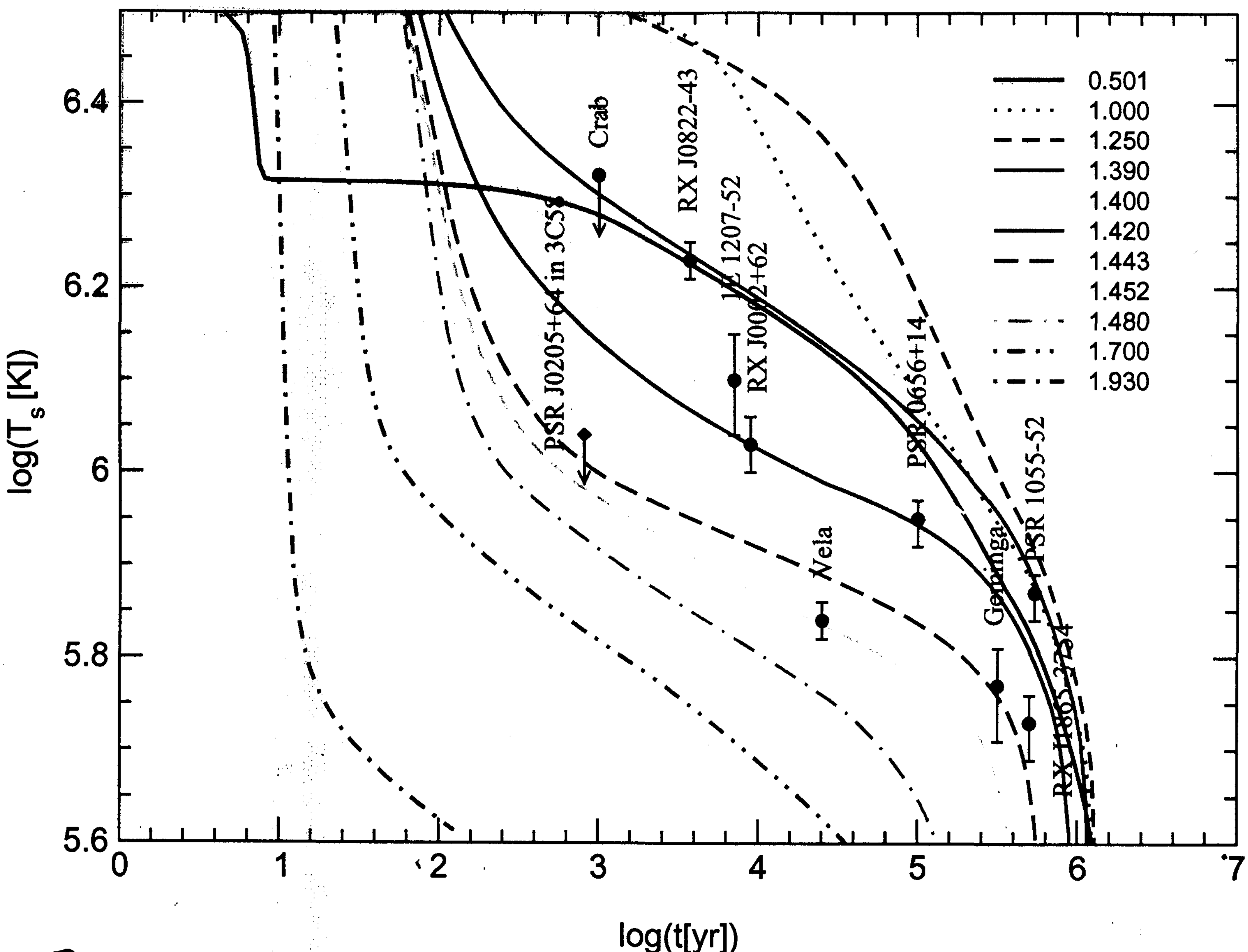


Fig 15 BGV (2004), $M \simeq 1{,}37 - 1{,}46\, M_\odot$

superfl. , med. ef. + PU

$0{,}5 \times {}^1S_0$ n

$0{,}2 \times {}^1S_0$ p

$0{,}1 \times {}^3P_2$ n

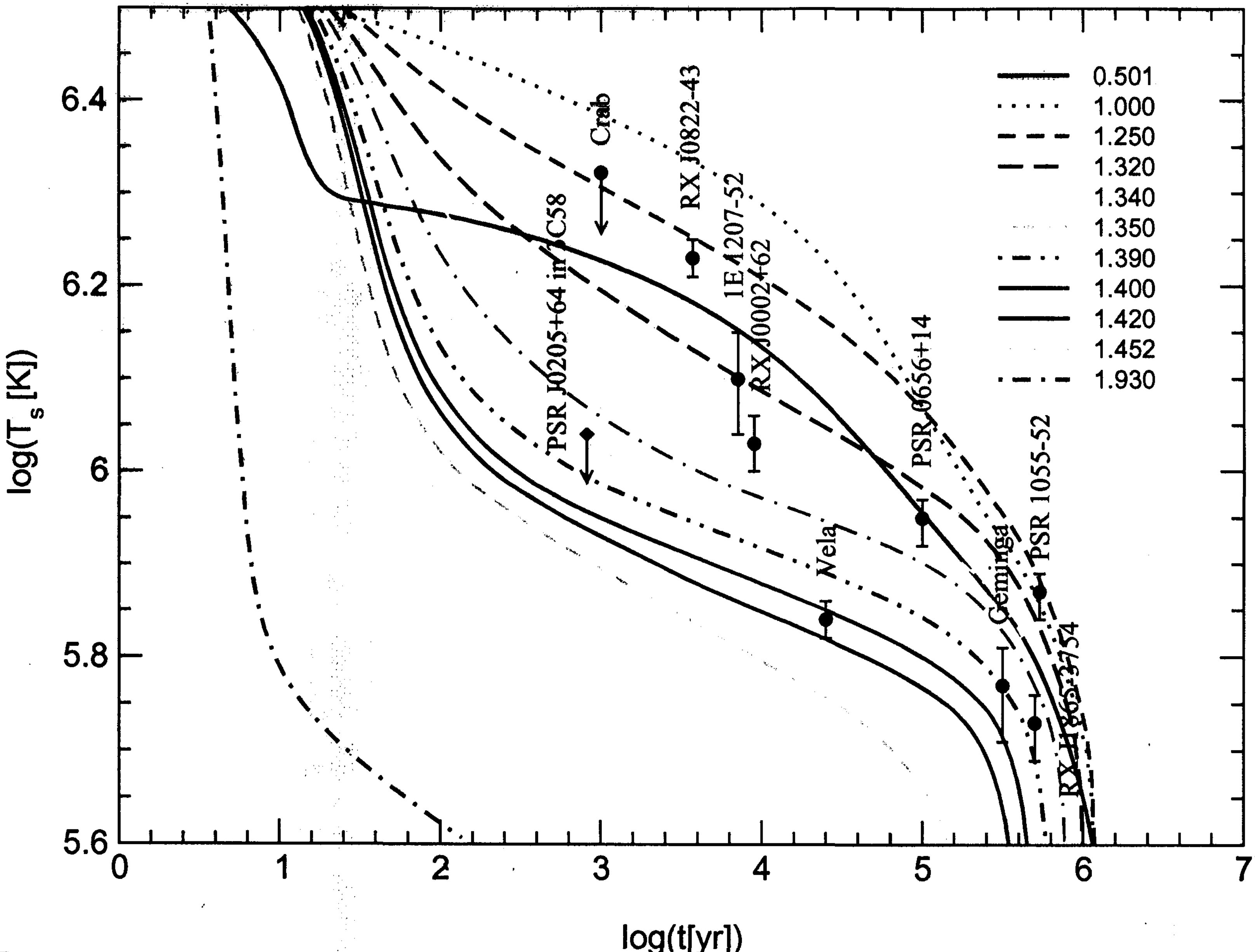


Fig 19 BGV(2004) $M \simeq 1{,}23 - 1{,}42\, M_\odot$

Superfl. , med. ef. without PU
0,1 × 3P₂ gap , Takatsuka, Tamagaki

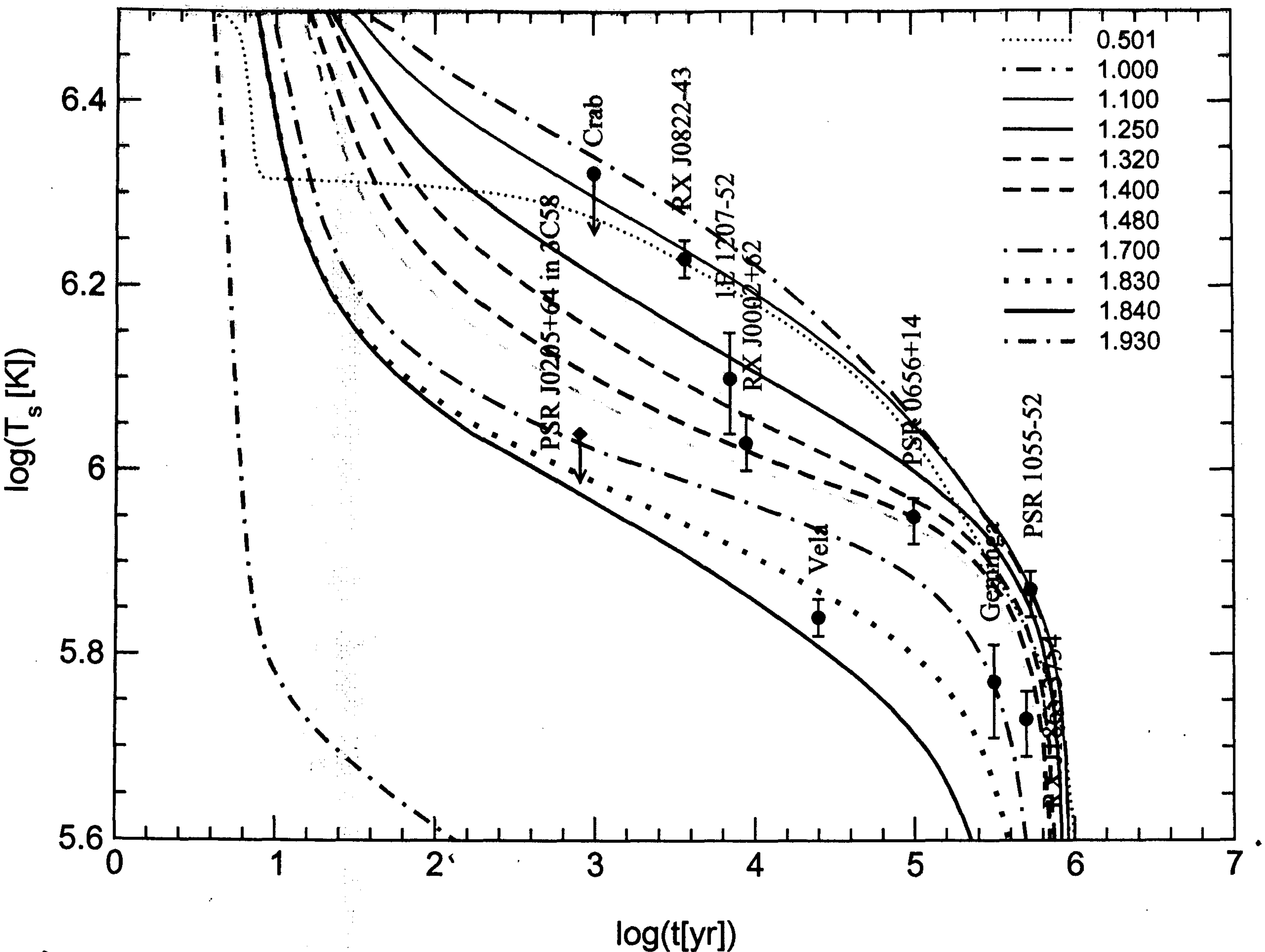


Fig 20 BGV(2004) $M \simeq 1{,}0 \div 1{,}84\, M_\odot$

superfl. , med. ef. + PU
0,1 x $^3P_2$ gap, Takatsuka, Tamagaki

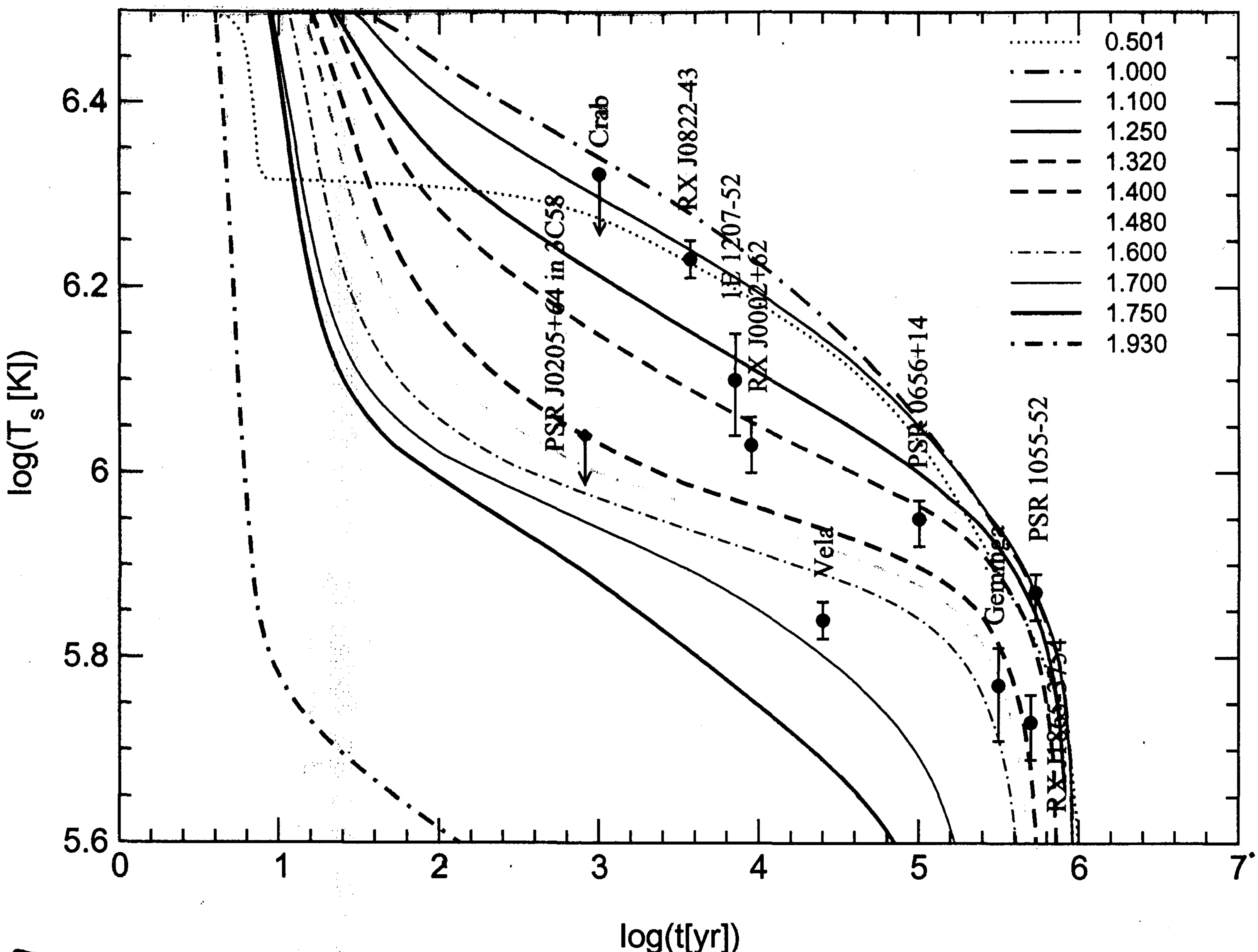
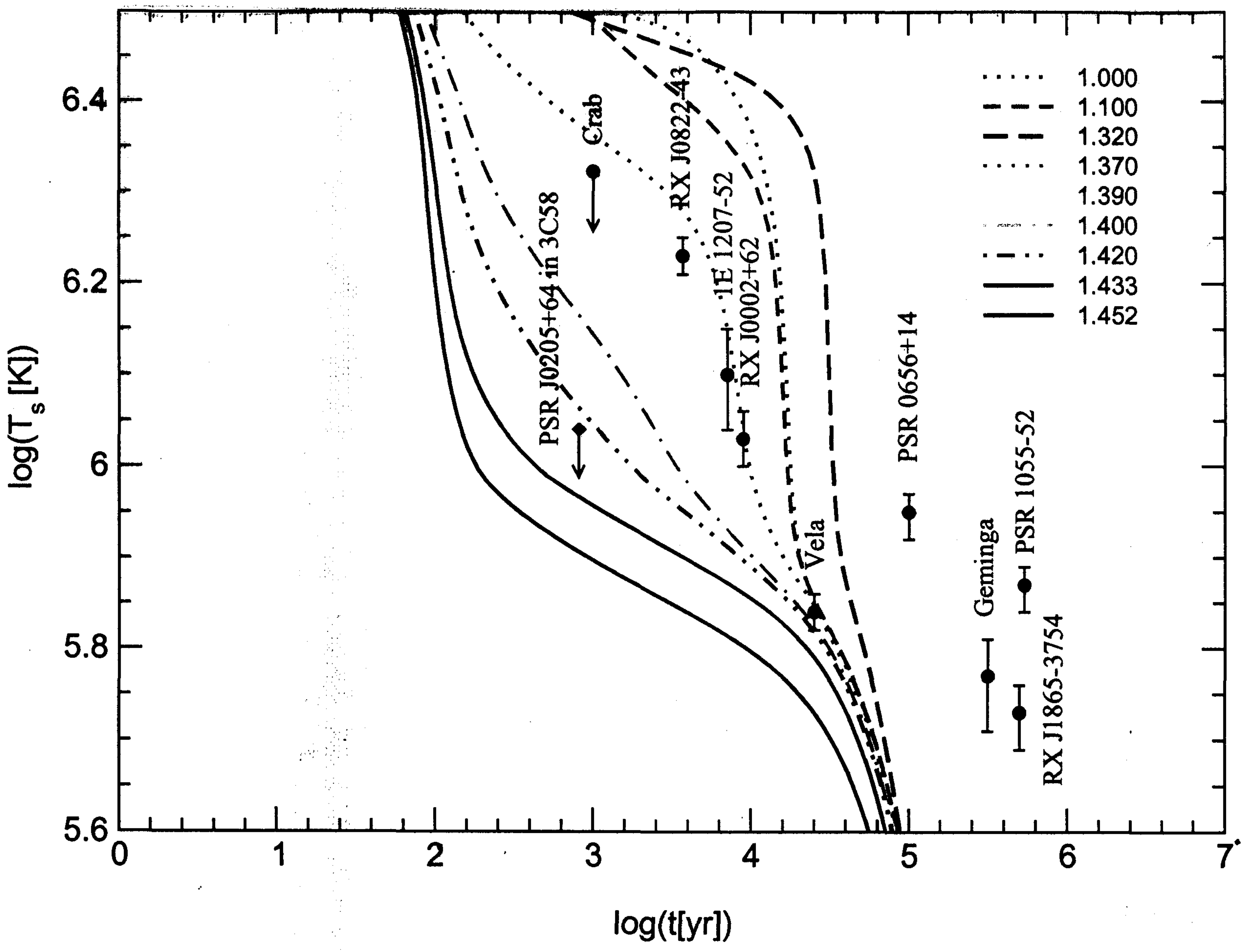
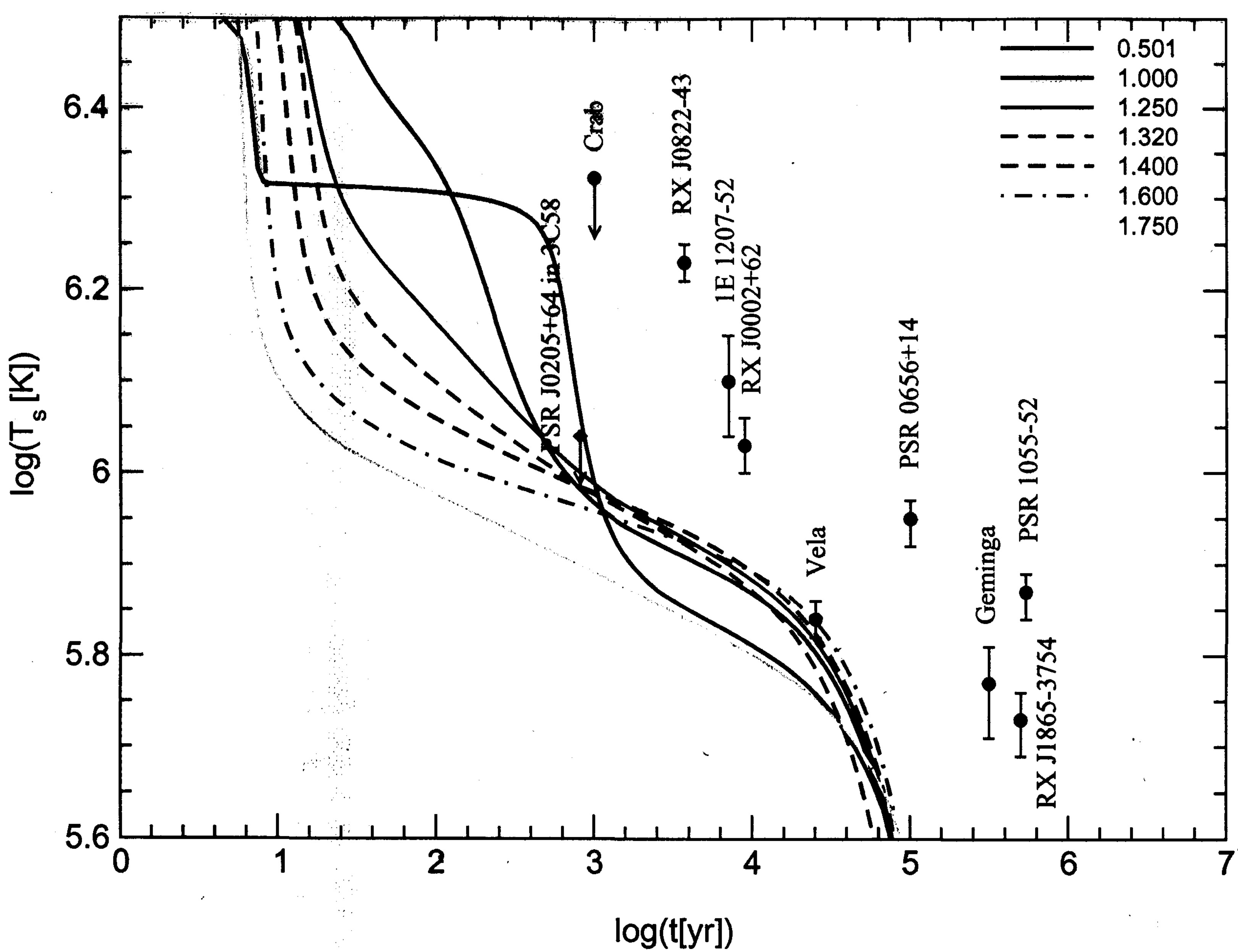


Fig 21 BGV(2004) $M \simeq 1{,}0 - 1{,}7\, M_\odot$

superfl., med. ef + PU
no suppression of $3P_2$ gap, Yak. et al



superfl., med. ef. + PU
no suppression of $3P_2$ gap, Takatsuka, Tamagaki



Conclusions

- Theoretically medium ef-s are called ~~for~~.
(No argument for „Standard + exotics" scenario except simplicity
- Normal matter assumption seems unrealistic (as theoretically, as from comparison with exp.)
- We support conclusion of Schwenk, Friman that $3P_2$ gap is strongly suppressed ($\lesssim 10$ keV) (in absence of re-heating)
- Comparison with data motivates medium ef-s (including pion softening)
- PU for $n \gtrsim 3n_0$ does not contradict data, n_c for „exotics" cannot be too low ($\lesssim 2.5\rho_0$)
- With medium effects – regular mass dependence.

Nucl. forces:

- LM local inter. + BB^{-1} + soft pion, kaon → self-consistent resummation of $BB + BB^{-1}$ + soft pion, kaon
  beyond QPA, like in Φ-derivable approaches
- Medium efs and EOS → $M_{lim} > 2{,}2 M_\odot$

{Pairing} • $3P_2$ gap with above constructed in-medium interaction
• proton gap

- Medium efs for $\nu\bar{\nu}$ trapping at initial stage of NS (1s-h) cooling. Possible ph. tr., second ν burst, relation to SN
- GRB model
- role of strong magnetic field: $B(t)$, cooling glitches. {Rotation field Ω}

Quark models

- going beyond bag, NGL including instanton, quark, gluon condensate efs
- CSC in strong coupling limit
  ph. tr. between different phases, mixed phases?, cooling